THE EFFECT OF IONIZING RADIATION ON ELECTROLYTE METABOLISM IN RATS

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The glucocorticoid function of the adrenal cortex is all important in connection with the action of ionizing radiation. Comparatively few works deal with the effect of ionizing radiation on mineral corticoid function. Indirect evidence on changes in this function following radiation has been produced by E. B. Pavlova and A. E. Rabkina [1] by giving a large water load; they found that on the second and particularly on the third and fourth days after the rats had been irradiated with the minimal absolute lethal dose of x-rays, the water was retained within the body, and diuresis was impaired.

Numerous reports [2-5] describe investigations into sodium and potassium metabolism in the tissues of irradiated animals, and the excretion of these electrolytes. However, the results are contradictory, probably because of different experimental conditions. The rate of formation and excretion of aldosterone, which is the hormone regulating mineral metabolism, may serve as an index of the state of mineral corticoid adrenal function after irradiation.

We have taken an initial step in this direction and have obtained results on the absorption of sodium in the intestine, the sodium and potassium content of the blood plasma, and the excretion of these electrolytes into the urine of irradiated animals.

METHOD

The experiments were performed on 250 male rats weighing 160-180 g. They were totally irradiated with a dose of 700 r from an RUM-11 apparatus. Irradiation conditions were as follows: current strength 15 ma, voltage 180 kv , focussing distance 40 cm , filter 0.5 mm Cu and 1 mm Al. The age of the animals ranged from 7 to 16 days. Both before and after irradiation, the animals were kept in glass metabolic cages with arrangements for the separate collection of urine and faeces. Collections were made before irradiation, and on the 1st, 3rd, 5th, and 7th days after irradiation. On the days when the urine and faeces were collected, the animals were not fed. Flame photometry* was used to estimate the sodium and potassium in faeces, urine, and plasma. An isotope method was used to measure the absorption of sodium from the intestine.

RESULTS

Table 1 shows the results of electrolyte excretion from the urine of the control and irradiated rats.

The average result for the sodim and potassium content of the urine excreted per day in healthy rats lay within the limits of figures published previously [6]. The amount of sodium and potassium excreted per day after irradiation deviates strongly from the normal; the sodium is much less, and the potassium much greater. The Na/K ratio has a value of 0.59 instead of the normal figure of 1.45.

On the third day, there was still an abnormal excretion of sodium and potassium, but the difference was that sodium was still more strongly retained; but because potassium excretion was also reduced the Na/K ratio remained the same as on the first day after irradiation. During this period there was no appreciable change in the diuresis.

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TABLE 1. Excretion of Sodium and Potassium into the Urine of Rats Before and After Irradiation

Date of determination	Number of rats	Amount of electrolytes in urine, per day in meq		
		sodium	potassium	Na/K ratio
Before irradiation (control)	108	0,58±0,07	0,4±0,025	1,45
1st day after irradiation	48	0,47±0,04	0,8±0,023	0,59
3rd " " "	42	0,33±0,045	0,55±0,03	0,60
5th " " "	33	0,64±0,11	0,32±0,05	2,0
7th " " "	24	0,56±0,10	0,52±0,056	1,07

In the following days we observed large individual variations in sodium and potassium excretion. It is worth noting that between the foruth and fifth days general symptoms of radiation sickness developed: some of the rats developed diarrhea, which by itself could cause considerable changes in electrolyte metabolism. It is therefore clear that the only results on the excretion of electrolytes which are valid are those which were obtained during the first three days after irradiation. In our opinion, the retention of sodium in the body and the increased excretion of potassium during this period are caused by an increase of mineral corticoid adrenal function. This idea is confirmed by experiments in which deoxycorticosterone acetate (DOCA) hormone, which has a mineral corticoid function, was injected.

A total dose of 5 mg of DOCA was injected in an oil solution for three days (1 mg on the 1st day, and 1 mg twice per day on the next two days). In all the animals the urine was collected on the third day after irradiation. The results are shown in Table 2.

TABLE 2. The Effect of DOCA on the Excretion of Sodium and Potassium in the Urine in Rats Before and After Irradiation

Experimental Conditions	No. of rats	Amount of electrolytes in urine, per day (in meq.)		
		Sodium	Potassium	Na/K ratio
Nonirradiated rats	108	0.58± 0.07	0.4± 0.025	1.45
Nonirradiated rats receiving DOCA	12	0.51± 0.06	0.43± 0.01	1.18
Peach oil injected 3 days after irradiation	9	0.36± 0.03	0.43± 0.01	0.83
DOCA injected 3 days after irradiation	24	0.16± 0.04	0.47± 0.03	0.34

Injection of DOCA into healthy rats has a negligible effect on sodium excretion. When DOCA is given to irradiated rats there is a great retention of sodium. In this case the effect of the irradiation and DOCA summate so that the Na/K ratio in the urine is reduced from its normal value of 1.45 to 0.34.

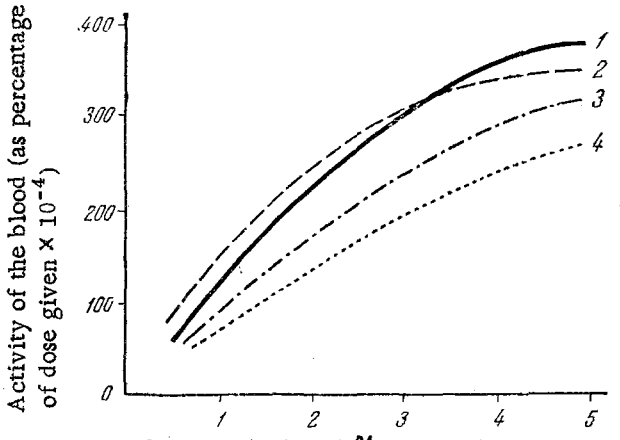
It might be expected that the marked shifts in the excretion of electrolytes with the urine would lead to corresponding changes in their amounts in the plasma. However, as can be seen from Table 3, such changes were insignificant.

The absence of any alteration in the sodium concentration in the plasma when excretion with the urine was reduced might be explained as being due to the reduced absorption of sodium from the intestine, or to an alteration in its distribution between cell and tissue fluid.

To examine the first possibility, we studied the absorption of sodium from the gastrointestinal tract, using the Na^{24} isotope. In many experiments, Na^{24} was introduced through a stomach tube and given to both control and irradiated rats; subsequently, after 15,30,60,120 minutes and later, blood was collected from the tail and its radioactivity determined. In other experiments, after the introduction of Na^{24} the body was screened with lead, and measurements of the radioactivity of the tail were made by means of an end-window counter with filter.

TABLE 3. Amounts of Sodium and Potassium in the Plasma of Control and Irradiated Rats

Date of determination	Number of rats	Amount of electrolytes, mg%	
		sodium	potassium
Before irradiation (control)	53	320	19,8
1st day after irradiation	51	320	18,5
3rd " " "	58	301	18,5



Activity of the blood in control and irradiated rats at different times after giving Na^{24}. 1) Control; 2) after 24 hours; 3) after 3 days; 4) 4 days after irradiating.

The results obtained by both methods agreed (see figure). In the first 24 hours after irradiating, the absorption of sodium remained normal, but by the third and fourth days it had been reduced. The fact that both the absorption of sodium and the plasma content remained within normal limits for the first day, while the amount excreted with the urine was reduced, appears to confirm the correctness of the view which has been reported elsewhere that both irradiation and increase of mineral adrenal corticoid function induced by other methods will lead to a liberation of potassium from cells and to its partial replacement with sodium ions from the extracellular fluid.

The following conclusions may be drawn. The effect of a minimum lethal dose of ionzing radiation applied to rats is to cause a reduced sodium and increased potassium excretion with the urine on the first and third days. During this time no appreciable changes occur in the plasma. On the third and fourth days after irradiation, less sodium is absorbed from the intestine. A total of 5 mg of DOCA given during the first three days enhances the effect of the radiation in increasing sodium excretion in the urine and leads to a marked reduction in the Na/K ratio.

These results, obtained shortly after irradiation, and before general symptoms of radiation sickness have developed, afford indirect evidence that mineral corticoid adrenal function is disturbed.

SUMMARY

Sodium and potassium urinary excretion were studied in rats irradiated with 700 r of x-rays. Na excretion was delayed and that of K increased during the first and third day after irradiation, causing a reduction in the Na/K ratio. No significant alteration in the concentration of these elements was noted in the blood plasma during the first few days after irradiation. Deoxycorticosterone acetate given to the rats after irradiation caused an even greater reduction in the Na/K ratio on the third day than did irradiation alone. Labeling with Na^{24} isotope confirmed that Na absorption from the intestine was delayed on the third and fourth days. Possibly disturbance of mineral corticoid adrenal function led to changes in mineral metabolism.

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